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ESTCP
Cost and Performance Report

(PP-0024)

Demonstration/Validation of Low Volatile Organic Compound (VOC) Chemical Agent Resistant Coating (CARC)

August 2004

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

COST & PERFORMANCE REPORT
ESTCP Project: PP-0024

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ACRONYMS AND ABBREVIATIONS

#/gal	pounds per gallon
AAAV	advanced amphibious assault vehicle
AFB	Air Force Base
AFRL	Air Force Research Laboratory
ALC	air logistics center
ARL	Army Research Laboratory
ASTM	American Society for Testing and Materials
C-E	communications-electronics
CAA	Clean Air Act
CARC	chemical agent resistant coating
CMM	Capability Maturity Model
COMSEC	communications security
COTS	commercial off-the-shelf
Dem/Val	demonstration/validation
DFT	dry film thickness
DFTM	dry film thickness measurements
DMB	Dry Media Blasting
DMTA	Dynamic Mechanical Thermal Analysis
DoD	Department of Defense
DS2	Decontaminating Solution 2
EO	Executive Order
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FCIM	Flexible Computer Integrated Manufacturing
FOV	family of vehicles
HAP	hazardous air pollutant
HEMTT	heavy expanded mobility tactical truck
HMMWV	high mobility multi-wheeled vehicle
HVLP	high volume, low pressure
IAW	in accordance with
LAV	light armored vehicle
LAV-AT	light armored vehicle – anti tank
LVS	logistics vehicle system

ACRONYMS AND ABBREVIATIONS (continued)

MCB	Maintenance Center Barstow
MCLB	Marine Corps Logistics Base
MEP	mobile electric power
NCO	isocyanate
NDI	non-developmental item
NESHAP	National Emission Standard for Hazardous Air Pollutants
NOV	notice of violation
NSN	national stock number
NSWC	Naval Surface Warfare Center
NSWCCD	Naval Surface Warfare Center, Carderock Division
OEM	original equipment manufacturer
OH	hydroxyl
OO-ALC	Ogden Air Logistics Center
OSHA	Occupational Safety and Health Administration
PASGT	Personnel Armor System, Ground Troops
PDM	programmed depot maintenance
PEI	principal end item
PI	Principal Investigator
PM	Project Manager
POC	Point of Contact
PPE	personal protective equipment
QPL	qualified products list
SATCOM	satellite communications
SERDP	Strategic Environmental Research and Development Program
SOR	source of repair
TRI	toxics release inventory
TYAD	Tobyhanna Army Depot
USMC	United States Marine Corps
UTTR	Utah Test and Training Range
VOC	volatile organic compound
WBCC	water-borne camouflage coating
WD	water dispersible
WFT	wet film thickness

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

When the Army first used the chemical agent resistant coating (CARC) system on tactical equipment in the early 1980s, it was in compliance with environmental regulations in effect at that time. However, federal and local regulations have since resulted in further restrictions in the amount of volatile organic compounds (VOC) and hazardous air pollutants (HAP) that can be emitted during the application and curing of protective coatings. The current approach to the problem is either to incur the high cost of procuring, installing, and maintaining an emission control system or to deviate from the CARC requirement and utilize a coating that meets environmental regulations but does not provide chemical agent resistance. The former approach can be economically prohibitive, and the latter approach results in a severe compromise to mission readiness.

The technology to be demonstrated/validated was developed primarily under the Strategic Environmental Research and Development Program (SERDP) Project PP-1056, Low VOC CARC, [1] which was initiated in FY97 and was funded by SERDP through FY99. Using recent developments in polymer and pigmentation technology, the Army Research Laboratory (ARL) was successful in developing a high performance, water-dispersible (WD) CARC polyurethane topcoat. The formulation developed under the SERDP Project succeeded in meeting the VOC objective of 1.8 pounds per gallon (#/gal) and has eliminated HAPs as well. In addition to being fully environmentally compliant, the new coating shows significant performance enhancements, as evidenced by improvements in mar resistance, low temperature flexibility, and weathering durability. U.S. Patent #5,691,410 has been awarded for the WD formula that was the basis of the SERDP effort.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this demonstration/validation (Dem/Val) was to prove out the application of the new WD CARC formulation to defense materiel under production conditions. The performance of the cured film was tested to satisfy the requirements of all three user services. In addition, stripping trials were performed to validate the ability to successfully remove the coating in a cost-effective manner.

The field demonstrations were conducted at three facilities, one for each of the services that will be utilizing the new WD coating. The following locations agreed to participate in this project:

Demonstration Site I—Navy/Marines - Barstow Marine Corps Logistics Base, California
Demonstration Site II—Air Force - Ogden Air Logistics Center, Utah
Demonstration Site III—Army - Tobyhanna Army Depot, Pennsylvania

1.3 REGULATORY DRIVERS

The Clean Air Act and its amendments have set the VOC limit for the CARC topcoat at 3.5 #/gal, but local governments are permitted to set lower limits and many have already done so.

Limits as low as 1.8 #/gal are required in some areas in order for the facilities to stay in production. Accordingly, the WD CARC was formulated to have a VOC no greater than 1.8 #/gal.

Guidance received from the U.S. Environmental Protection Agency (EPA) has indicated that the Miscellaneous Metal Parts and Products Surface Coating National Emission Standard for Hazardous Air Pollutants (NESHAP) will apply to CARC. This would require that the HAPs such as methyl isobutyl ketone, toluene, and xylene that are used in the current formulation must be removed or eliminated with add-on emission controls. The new WD CARC formulation has eliminated these solvents through the use of such non-HAP solvents as Exxate 600 (oxo-hexyl acetate) or Exxate 700 (oxo-heptyl acetate), in addition to the overall reduction in VOC content.

The reformulation of the CARC topcoat addresses official Department of Defense (DoD) requirements by a 50% reduction in VOCs, the elimination of HAPs, and the absence of ozone-depleting compounds. Furthermore, emphasis was placed on validating the use of nonhazardous stripping methods, such as media blasting, as opposed to the use of chemical strippers.

1.4 DEMONSTRATION RESULTS

Application demonstrations were held at the three depot facilities noted above from May 2000 to November 2000. The WD CARC used was from production batches manufactured by the Sherwin-Williams Company, and it was applied using standard production equipment under normal environmental conditions. Production stripping demonstrations were held at these same production facilities from July 2001 to November 2001 using aged test panels prepared during the application demonstrations. The demonstrations verified that the WD CARC is essentially a "drop-in" substitute for the current solvent-based CARC, because it could be applied and stripped using existing equipment and processes at the depot facilities. Surveys completed by the depot applicators indicated that the WD CARC was considered overall to be a better coating than the standard CARC normally used, with up to one-third less paint required for individual items painted. New disposal options were not investigated for the nonchemically stripped CARC.

The exceptional performance of the coating noted in the SERDP effort, especially its flexibility, mar resistance, and outdoor durability, was confirmed at the production level. This improved performance should lengthen the time between refinishing, mitigate surface damage due to abrasion, and result in less refinishing of military equipment on the basis of cosmetic appearance. While process changes at the demonstration sites made stripping comparisons more problematic, the data support the fact that strippability falls within normal production limits, and the use of WD CARC will not present a serious impact in any military depot.

A new specification, MIL-DTL-64159 (dated January 20, 2002), was prepared and published shortly after the conclusion of this ESTCP Demonstration Project. This specification will provide a means of procurement of the new topcoat. The qualified products list (QPL) for the specification, QPL-64159, was first published February 28, 2002, and the current revision includes four suppliers. In addition, ARL has completed the revision of the CARC quality control and application specification, MIL-DTL-53072C (formerly MIL-C-53072B), and it now

incorporates MIL-DTL-64159. National stock numbers (NSN) are available for four different kit sizes and are included in MIL-DTL-53072C. Many facilities, both DoD and original equipment manufacturers (OEM), have indicated that they use MIL-DTL-53072 to implement CARC, and inclusion of MIL-DTL-64159 will facilitate use of the WD CARC technology.

Operational costs for the WD coating were tracked and compared to those of the current CARC. When an extension in life cycle for programmed maintenance was considered, they were lower than for the standard CARC, and it was estimated that annual cost savings of $0.38 to $0.73 million would be realized by each DoD facility implementing WD CARC.

1.5 STAKEHOLDER/END-USER ISSUES

End users of this technology include program managers, OEMs, and depots that are required to follow Army Regulation 750-1 [2] (also followed by the Marine Corps) for chemical warfare survivability. This regulation requires that all tactical equipment (including combat, combat support, essential ground support equipment, tactical wheeled vehicles, and aircraft) must be hardened against performance degradation caused by chemical warfare agents or decontamination procedures. Therefore, virtually the entire Army and Marine Corps inventory, plus Air Force vehicles and equipment procured through the Army require chemical agent resistance.

Currently used CARC coating formulations contain 3.5 #/gal of VOCs. The current annual usage nationwide is estimated to be 3.0 million gallons per year. A CARC targeted to a 1.8 #/gal VOC limit would save at least 5 million pounds of VOC per year in the application of the coating, proportionately reduce photochemical smog generation, and avert notices of violation (NOV) at user facilities, which include depots, air logistic centers (ALC), military bases and OEMs. By developing one CARC topcoat for use by all the services, substantial savings will result in procurement and logistics operations. Since the WD CARC is a superior product (enhanced flexibility, mar resistance, and weathering durability) compared to current CARC, it is expected that its service life will greatly exceed that of the current material and therefore will not require stripping and repainting as often.

With some DoD facilities already prohibited from using CARC topcoats because of existing regulations and other facilities having been forced to install emission control systems in order to stay in production, many users have already sought the WD CARC technology. Moreover, as the NESHAP applicable to most uses of CARC coatings is enforced, the use of the current CARC topcoat will become further restricted both at the OEM level and by the depot community. Implementation of WD CARC was expedited by this ESTCP program because the material was used and evaluated in a production environment, thus alleviating concerns that are inherent when a new technology is introduced, providing a hands-on technology transfer opportunity and eliminating the need for the use of emission control systems.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

The components of a typical coating can be divided into three main groups. The polymer (commonly called the binder) provides the required performance level of the product, the pigments provide the desired color and gloss, and the solvents/additives control package and application viscosities and aid in film formation. In a typical solvent-based urethane system, a polyol reacts with a polyisocyanate to form a polyurethane. In CARC, the aliphatic polyurethane binder [1] provides the chemical agent resistance, and the camouflage properties are provided by the appropriate selection of tinting pigments for visual color and near-infrared reflectance, plus extender pigments for gloss control. The low gloss requirements for camouflage topcoats typically lead to a proportionately higher pigment to binder ratio. This works against the performance provided by the polyurethane polymer. Typical extender pigments are silica-based (siliceous), and they provide relatively inexpensive gloss reduction, but at the expense of poor mar resistance and flexibility, particularly at the high loading levels in camouflage topcoats. In evolving toward replacement of these extenders with non-siliceous varieties, multiple sources of supply and composition were considered, along with several blends of polymeric and siliceous extenders. After polymeric beads with satisfactory performance were discovered—especially with resistance to Decontaminating Solution 2 (DS2), alkali, hydrocarbons, and acids—performance (primarily flexibility and mar resistance) was the primary criterion in judging acceptability in the coating. In general, however, the most dramatic performance improvements came about due to total replacement of the siliceous portion of the extender system. This was made possible because of the greater efficiency in flattening (gloss control) associated with the polymeric beads; i.e., for a given gloss level, less weight and volume were necessary than for siliceous extenders. This led, in turn, to a more resin-rich film, with the expected improvements in performance.

2.2 PROCESS DESCRIPTION

The generic (bifunctional) urethane reaction is given by:

$$\underset{\text{(polyisocyanate)}}{OCN-R-NCO} + \underset{\text{(polyol)}}{HO-R'-OH} \rightarrow \underset{\text{(polyurethane)}}{-[-CO-NH-R-NH-CO-O-R'-O-]-}$$

If designed properly, crosslinking in this system provides high performance coatings such as CARC. However, the necessity to ensure that water is not present in nonaqueous, two-component polyurethane formulations has been paramount because of its reaction with isocyanate. The reaction forms an unstable carbamic acid, which quickly decomposes to generate carbon dioxide and an amine. In a solvent-borne, two-component system, this reaction may inhibit or adversely affect the stoichiometry and development of crosslinking that is crucial to the integrity and performance typical of two-component polyurethanes. However, recent developments in raw materials for waterborne polyurethane technology, particularly by the Bayer Corporation, have enabled high-performance coatings to be formulated using water dispersible polyisocyanates and hydroxyl-functional polyurethane dispersions [5]. While there is

a competing reaction occurring with water, the kinetics, raw materials and proper indexing, the ratio of isocyanate (NCO) to hydroxyl (OH) groups used in the formulations, ensure that sufficient crosslink density is established in the film.

Typically, water-borne formulations are indexed at an NCO to OH ratio ranging from 1.5 to 3.5, well above the 1.1 typical of solvent-based systems. Early efforts at ARL focused on formulations with NCO to OH ratios between 2.0 and 3.5. While these films exhibited enhanced properties compared to the solvent-based coating, they did not have sufficient performance to pass the Army's chemical agent resistance requirement. For this reason, further investigation led to the most recent formulations with NCO to OH ratios of 5.0. This level of indexing provided chemical agent resistance without a significant change in coating properties. The formulation efforts involved a significant amount of research in the area of additives, pigmentation, and dispersion techniques to assemble a camouflage topcoat that has significantly improved performance properties and offers state-of-the-art technology with respect to environmental compliance for industrial maintenance type coatings. This research effort has resulted in a patent award (U.S. Patent #5,691,410) for the coating. [3] While the original goals were VOC reduction and HAP elimination, use of the WD polymer system and elimination of the problematic extender pigments used in typical low-gloss coatings led to remarkable improvements in performance.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

Testing the application and stripping properties of the WD CARC was performed under SERDP Project PP-1056. [1] Although the new WD CARC was applied and stripped using production-type equipment, the work was carried out in laboratory environments. The SERDP work indicated that the new formulation was compatible with production processes, but this needed verification by production operators in production facilities under a variety of climatic conditions.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The substitution of an environmentally compliant CARC provides a simple, drop-in solution to the environmental problems associated with painting military equipment, including (but not limited to) VOC reduction, HAP elimination, and the consequent elimination of emission control equipment. It requires no specialized application equipment and can be used anywhere. It has been established that the new coating can be applied using the techniques common to depots and OEMs, i.e., conventional spray and high-volume, low-pressure (HVLP) spray guns.

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The performance objective of the demonstrations was to replace the current topcoat (either MIL-C-46168, MIL-C-53039, or MIL-C-29475) with the WD CARC and to validate that the new topcoat is a drop-in replacement that meets or exceeds the performance requirements of the current material (see Table 2 and Table 3 in Section 4). Through the execution of the applicable documents as defined below, the application of the WD CARC was accomplished for selected defense equipment (typically 3 to 5 units at each demonstration site) and a designated number of test panels to validate the performance of the coating and the stripping processes and obtain the metrics necessary to conduct performance and cost analysis. Through direct comparison with the current CARC topcoat as applied and stripped at the demonstration sites, an analysis was made to determine if there is a deviation from a drop-in substitution, and if so, what the cost implications are.

3.2 SELECTION OF TEST PLATFORM/FACILITY

The field demonstrations were conducted at three facilities, one for each of the services that will be using the new WD coating. Sites selected were identified by their need, interest, and qualifications to conduct the demonstrations. Also, an attempt was made to vary the geographical locations to demonstrate the technology under varying climatic conditions.

At the Marine Corps demonstration site, Barstow Logistics Base, CA was unable to use any CARC topcoat because environmental considerations and was using a waterborne polyurethane coating that was not chemical agent resistant. The facility was interested in evaluating the WD CARC topcoat. Also, the location in the Mojave Desert represents an extreme (dry) climatic condition. This site had been used previously by the Marine Corps and Navy to demonstrate new coating materials and had performed admirably in this capacity.

The Ogden Air Logistics Center site in Utah is the only Air Force site where CARC topcoat is currently being applied. Thus, it was in an excellent position to compare the drop-in nature of the new coating for their facility.

The Army demonstration site selected was the Tobyhanna Army Depot in Pennsylvania. It is a large-scale user of CARC topcoat and is the Army Center of Excellence for painting for the depot community. Also, the site provided a relatively humid environment that added to the desired variety in climatic conditions of the demonstration sites.

3.3 TEST PLATFORM/FACILITY CHARACTERISTICS/HISTORY

3.3.1 Maintenance Center Barstow

Maintenance Center Barstow (MCB) is an industrial facility in the Mojave Desert approximately 150 miles southwest of Las Vegas, Nevada, and 120 miles east of Los Angeles, California. It is located in a desert climate with an average relative humidity between 8% and 21%, and the

temperature averages between 106° F and 112° F in the summer and between 28° F and 58° F in the winter. The Final Paint Facility of MCB consists of three paint booths (one 60-foot booth and two 30-foot booths), 10 permitted paint areas, and one drive-through drying oven. Pollution prevention technologies include an air pollution control system from Terra-Aqua Enviro Systems, with a total volume of 42,000 cu. ft. being treated. There are only two other similar facilities in the state of California.

The facility is located on the Marine Corps Logistics Base (MCLB) Barstow in Barstow, CA. This is a Depot Maintenance Activity for the Marine Corps, providing all echelons of maintenance support to Fleet Marine Forces west of the Mississippi and from the Pacific regions. Final Paint provides coating operations for all principal end items (PEI) including surface cleaning and preparation, and application of base coat, prime coat, and topcoat. These processes represent the major waste stream generators within the facility. The vehicle mix includes all ground tactical equipment such as: M1A1, M-88, AAVP7 tanks, light armored vehicles (LAV), all variants of 5-ton trucks, all variants of the high mobility multi-wheeled vehicle (HMMWV), logistics vehicle system (LVS) family of vehicles, and construction and engineering equipment. Cleaning and preparation processes include steam cleaning, abrasive (steel shot, garnet, plastic media) blasting, and minimal chemical stripping. The MCLB has sprayed everything from enamels, lacquers, and chromates in the early 1960s to alkyds, epoxies, chemical agent resistant coatings, and polyurethanes in the 1980s. Increasingly stringent VOC restrictions have prohibited the use of various coatings in significant quantities. One of these coatings is the CARC topcoat, MIL-C-46168. At the time of the Dem/Val, the MCLB was spraying low-VOC waterborne camouflage coatings (WBCC), epoxies, polyurethanes, and limited amounts of CARC.

3.3.2 Ogden Air Logistics Center

Ogden Air Logistics Center (OO-ALC) is centrally located in the western United States within the northern population center of Utah, approximately 30 miles north of Salt Lake City and 15 miles south of Ogden. It is situated at 4,800 feet above sea level in a semi-arid region having four distinct seasons. It contains a total of 962,132 acres of land in three areas:

Area A: Hill Air Force Base (AFB) consists of 6,683 acres with 1,375 buildings, of which 229 are industrial containing 4 million square feet.

Area B: Utah Test and Training Range (UTTR), located approximately 90 mile west of the base, consists of 953,887 acres with 122 buildings, of which 45 are industrial with 234,261 square feet.

Area C: Survivability & Vulnerability Integration Center, located 220 miles northwest of the base, has 740 acres with 17 buildings, of which four are industrial with 2,902 square feet.

OO-ALC provides worldwide logistics management, engineering, modification, and depot maintenance for the F-16 Fighting Falcon aircraft, including logistics support to 19 countries and more than 3,900 F-16 aircraft. OO-ALC also provides programmed depot maintenance on the C-130 Hercules, logistics management for the F-4 aircraft, including support to eight countries, and is the repair source and logistics manager for the nation’s silo-based intercontinental ballistic

missiles, including the Minuteman and Peacekeeper. OO-ALC operates the largest overhaul facility for aircraft landing gear, wheels, and brakes as well as a state-of-the-art composite repair facility. Items overhauled include rocket motors, air munitions, guided bombs, photonic imaging and reconnaissance equipment, shelters, and other related components. In addition, OO-ALC has a premier software development, test maintenance, and consultation capacity with a Level 5 Capability Maturity Model (CMM) rating. Principal end items maintained by OO-ALC are the F-16 Fighting Falcon, the C-130 Hercules, the LGM-30 Minuteman, and the LG-118A Peacekeeper.

3.3.3 Tobyhanna Army Depot

Tobyhanna Army Depot (TYAD) is the largest full-service communications-electronics (C-E) maintenance facility in the Department of Defense, with more than 3,000 employees. There are 143 buildings in the industrial complex. The depot's mission includes the design, manufacture, repair, overhaul, and fabrication of hundreds of communications and electronics systems. Communications-electronics systems supported by Tobyhanna include communications, command and control, surveillance and target acquisition, airborne electronics intelligence and electronic warfare, electronic support equipment, and power systems. TYAD is a leader in the areas of automatic test equipment, systems integration, and the downsizing of military communications-electronics systems. Responsibilities include Communications-Electronics source of repair (SOR) for such products as communication systems, command and control systems, surveillance and target, acquisition systems, avionics systems, intelligence and electronic warfare systems, automatic data processing systems, power systems, and electronic support equipment and systems. It has the special mission for satellite communications (SATCOM) support and communications security (COMSEC) support, and offers fabrication support for flexible computer integrated manufacturing (FCIM), non-developmental item/ commercial off-the-shelf (NDI/COTS) equipment ruggedizing and hardening, C-E systems downsizing and prototyping, installation kits, circuit card assemblies, equipment rack systems, switch/junction boxes, distribution boxes/panels, mobile equipment power plants, power units/generators, and textile goods fabrication.

3.4 PHYSICAL SET-UP AND OPERATION

The overall goal of this Dem/Val was to show that the results of the prior SERDP effort, with laboratory-size coating preparation and pilot-plant-size application, could be readily scaled up to full-scale manufacture by a partner coatings manufacturer and application on the production level at the demonstration sites. Consequently, the baseline for comparison was the standard CARC in use at each facility, and the necessary data (such as the amount of paint required for each piece of hardware) could be obtained from records at each facility. From the strippability standpoint, the goal was much the same, i.e., to verify that data gathered in the laboratory-scale SERDP program could be scaled up to the production level. However, during the time between the baseline studies and the stripping Dem/Val efforts, significant changes occurred in the coating systems and the stripping methods used at the demonstration sites, making direct comparisons difficult in many cases. The coating differences involved the assumption that the epoxy primer used was the solvent-based MIL-P-53022, versus the water-reducible MIL-P-53030 actually used at Barstow and Tobyhanna. In addition, some of the stripping media used at

all three facilities during the Dem/Vals were different from those used during the baseline work. The schedule for the demonstrations is provided in Table 1.

Table 1. Demonstration Dates.

Site	Application Demonstration	Stripping Demonstration
Maintenance Center Barstow	May 9–11, 2000	July 16–19, 2001
Ogden Air Logistics Center	August 28–30, 2000	October 22–24, 2001
Tobyhanna Army Depot	October 30–November 1, 2000	November 5–6, 2001

Site preparation activities were routine, included equipment set-up, and provided analytical instrumentation and the required utilities. At all three Dem/Val sites, normal production application and stripping equipment were used for the application and the stripping operations. These included hardware (application and stripping equipment) paint application facilities, stripping booths, and personal protective equipment (PPE). Prior to coating the defense equipment and panels, the demonstration site personnel practiced application of the WD CARC using scrap hardware. This helped expedite fine-tuning their application techniques and enabled adjustments (fluid fan width, fluid nozzle size, air line pressure, and stand-off distance) to be made to optimize the application process before coating the defense equipment and panels.

3.5 SAMPLING/MONITORING PROCEDURES

The only process change during an application demonstration was substituting WD CARC for the topcoat normally used. At all three demonstration sites, the normal contingent of painters worked in the application booth and wore the normal PPE. Records were kept of the hardware coated, the spray application equipment used, the surface preparation applied to the substrate, the paint used, the environmental conditions at the time of application, and the timing of the events. The Naval Surface Warfare Center, Carderock Division (NSWCCD) developed a Marine Corps Experimental Coating Data Sheet for this purpose. In addition, immediately after finishing the paint application process, each painter completed a WD CARC Field Trial Application Survey, also developed by NSWCCD. The survey asked questions about the mixing and spraying characteristics of the WD CARC as compared to the coating normally used and for an overall general opinion of the WD CARC as compared to the solvent-based CARC. Similar record keeping was performed during the stripping demonstrations, which occurred approximately a year after the application demonstrations (see Table 1). The normal schedule for an application demonstration was to apply the pretreatment and primer to the equipment and test panels on the day before the application of the WD CARC, either in the presence of the ESTCP team or prior to their arrival. The topcoat application was performed the following day, and an additional day was reserved for examining the coated panels and equipment, preliminary measurements of film properties on the hardware (such as dry film thickness and gloss), application of topcoat to remaining equipment, and outbriefings. Each stripping demonstration was set up for a single day with one backup for examination of panels in chemical stripper baths (when applicable) and outbriefings. See Table 2 and Table 3 in Section 4 and Appendix B of the Final Report [4].

3.6 ANALYTICAL PROCEDURES

The performance of the WD CARC was evaluated with a variety of methods, including those appropriate to the application process, to the performance of coated test panels prepared during the application process, and to the stripping process as performed on aged coated test panels. The common test descriptions were the descriptions of the test procedures performed on the test panels and were used to assess the performance of the WD CARC applied during the application demonstration. The WD CARC Field Trial Application Survey obtained the painters' evaluation of the preparation, application, and cleanup of the WD CARC as compared to the coating they normally used. The Field Trial Panel Matrix listed the test panels coated during the application demonstration that were provided by the team members for later performance testing. A U.S. Marine Corps Experimental Coating Data Sheet tracked the equipment painted, the surface preparation used, the coating system applied, and the environmental conditions at the time of application.

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4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

While direct comparison of the ESTCP stripping demonstrations to the baseline data developed in the SERDP effort were in many cases not possible because of process differences and different primers, the data from the application demonstrations were positive. The overall results confirm that the WD CARC is a suitable replacement for standard CARC with minimal disruptions to the production process. In addition, it offers significant VOC reduction, HAP elimination, and vastly improved performance.

4.1.1 Barstow MCLB

The WD CARC was first applied to the test panels (shown in Figure 1) on May 10, 2000. After the panels were coated with WD CARC, a large quantity of "fish eyes" were discovered on the painted surface. The painters were requested to flush their paint lines with a water/alcohol mixture to ensure that their lines were not the source of contamination. However, fish eyes still occurred when the paint was reapplied. A discussion with the painters revealed that the guns, Binks HVLP Mach 1 model, had been soaked in oil to prevent seizing of the parts. The ESTCP team requested that new guns — same model, make, and type — be used for the remainder of the demonstration. With the new oil free equipment, the coating was applied without fish eyes or other defects. The average wet film thickness (WFT) applied was approximately 5 mils. It was noted that after 24 hours of cure time, the coating film on the panels appeared continuous and even, with no obvious defects.

The vehicles were then coated using the new equipment on May 10, 2000. The first two batches of paint mixed at two parts Component A to one part Component B to 0.75 parts water (2:1:0.75 mix ratio) were applied to two HMMWVs. With the new equipment, the application to all vehicles proceeded without defects. Data were gathered on the process using the Experimental Coating Data Sheet. Three runs or sags were noticed on each vehicle, which was acceptable considering that this was the painters' first use of the material. On the same day, the third and fourth batches of paint were mixed. The mixing process was the same as that used on the first batch, except only two quarts (0.5 parts) of water was added (2:1:0.5 mix ratio). This water concentration adjustment was based on the expertise of the painters, who determined that the viscosity was slightly lower than optimal for their application techniques and process goals. This paint was used for application to a 5-ton truck. Eight runs or sags were noted on this vehicle, which, as with the HMMWVs, is acceptable. The increase in the absolute number of sags is tempered by the size of the vehicle and thus the amount of material applied to the truck.

The last vehicle to be coated with the WD CARC was a Light Armored Vehicle-Anti-Tank (LAV-AT). The MCLB was performing final touch-ups on the primer in the morning of May 11, 2000. The supply of the routinely used primer MIL-C-53030 had been depleted, and Kar Products spray primer, a phenolic linseed alkyd resin enamel, was substituted. Upon completion of the touch up, two batches of the WD CARC were mixed, with mix ratio 2:1:0.5, for successful application to the LAV (Figure 1). It was determined that approximately 2.5 gallons of paint was

used for each HMMWV. Approximately 6 gallons of paint was used to coat the 5-ton truck. The LAV application also consumed approximately 6 gallons of paint.

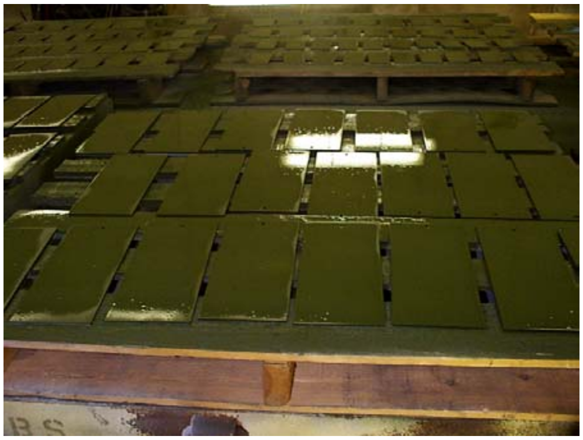

Figure 1. WD CARC Applied to Test Panels (left) and to a Light Armored Vehicle (right).

Applying WD CARC on the four vehicles at MCLB Barstow demonstrated the WD CARC system's drop-in nature. The WD CARC was applied to the vehicles with application performance similar to the standard CARCs. The surveys completed by the depot applicators at MCLB Barstow indicated that the WD CARC was considered overall to be a better coating than both MIL-C-46168D and MIL-C-29475. Laboratory testing on the coated panels produced test results similar to the SERDP program testing of the baseline WD CARC.

The dry film thickness (DFT) values obtained on the vehicles indicated that obtaining the proper film build requires using a lower water concentration mix ratio (2:1:0.5). Therefore, the recommended mix for WD CARC is 2 parts A: 1 part B: 0.5 part water, providing environmental conditions and equipment allow. Any increase in the amount of water should be made in small increments to avoid unnecessary recoating.

Testing performed on the panels prepared in the application demonstration verified the exceptional performance that the coating showed in the SERDP effort. The final report [4] contains detailed results.

4.1.2 Ogden ALC

The WD CARC was applied to the prepared test panels first, then to three MEP 007B generators and an MEP 005A generator. Application went smoothly. Figure 2 shows the test panels before they were painted and WD CARC being applied to an MEP 007B generator.

The application of WD CARC to four mobile electric power (MEP) units at Ogden ALC demonstrated the drop-in nature of the WD CARC system. The WD CARC was applied to the vehicles with similar application performance compared to the standard CARC topcoats. The surveys completed by the depot applicators at Ogden ALC indicated that the WD CARC was considered overall to be a better coating than the current MIL-C-46168D solvent-borne CARC,

though they did not like the additional mixing step. In addition, the laboratory testing completed on the coated panels resulted in similar test results to the SERDP program testing of the baseline WD CARC.

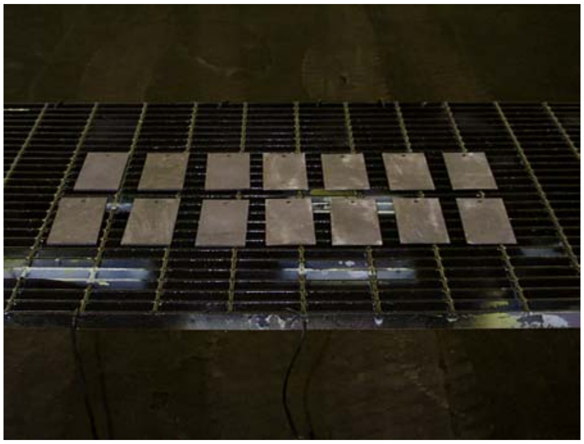

Figure 2. Test Panels Before Applying WD CARC at Ogden (left) and WD CARC Being Applied to an MEP-007B Generator (right).

The painter and facility personnel said the WD CARC went on much more smoothly than the standard CARC, and they felt it covered more surface area. Dry film thickness measurements (DFTM) taken at various points on the MEP units showed that the DFT of the WD CARC topcoats for the units ranged between 1 and 4.2 mils, with an average of 2.25 mils for the MEP 007B units. DFTM for the MEP 005A ranged between 1.2 and 4.6 mils, with an average of 2.73 mils. A second set of test panels from NSWCCD, which had been lost in shipping, was located and painted to evaluate the sag resistance of the WD CARC. The WD CARC did not show the same type of sagging seen in the SERDP application testing and in the Barstow Dem/Val.

Testing performed on the panels prepared in the application demonstration verified the exceptional performance that the coating showed in the SERDP effort. The final report [4] contains detailed results.

4.1.3 Tobyhanna Army Depot (TYAD)

The application of the WD CARC to varied military hardware at Tobyhanna Army Depot demonstrated the drop-in nature of the WD CARC system. Before the TYAD painters painted the selected equipment, they practiced on various substrates in the spray booth to familiarize themselves with WD CARC application properties, using, in all cases, Graco Delta 2000 HVLP siphon-feed cup guns. They then painted the primed test panels (Figure 3) for subsequent performance testing. The equipment had been appropriately prepared for topcoat application. The following components were painted on October 31, 2000:

- 3 small 9,000-BTU AC units, each approximately 26″L x 26″W x 16″H
- 1 large antenna pedestal base (#3199), pyramidal-frame-shaped, each leg approximately 4′-5′

- 1 Small Tripod (each leg approximately 3′ long)
- 4 AN/TRC-170 Antenna Trailer components (approximately 5′L, approximately 1′ diameter)
- 4 Legs to a 5-ton fuel trailer (approximately 3′ L, 12′ base, 6″ approximately diameter shaft)
- 2 Gichner Mobile Systems GMS-250 shelter

Although an occasional sag was observed, application went well. Figure 3 shows WD CARC being applied to one of the GMS-250 shelters. In general, atomization, leveling, and film formation were satisfactory whereas the tendency of a paint to sag or run depends on the technique of the applicator in making adjustments to his equipment and on the design of the items being painted (i.e., recessed areas, sharp edges, raised rivets, etc.). The painters learned quickly how much wet coating to apply to provide the needed dry film thickness of about 2 mils without generating sags. They used 2.75 gallons in painting the various components and test panels.

On November 1, 2000, one Gichner Mobile Systems GMS-280 shelter (with approximate dimensions of 12′ L x 6′ W x 7′ H) was painted. As with the day before, the painters indicated that the coating applied well although a few sags were observed. On most of the solvent flashing off, the film was uniform with few defects.


Figure 3. Test Panels Before Applying WD CARC at Tobyhanna (left) and WD CARC Being Applied to a GMS-250 Shelter (right).

Surveys completed by the depot applicators indicated that the WD CARC was considered overall to be a better coating than the MIL-C-53039 normally used, although the mixing of the WD CARC with regard to the complexity, ease, and time required was slightly worse. Laboratory testing completed on the coated panels indicates similar test results to the SERDP program testing of the baseline WD CARC. This improved performance in outdoor durability should lengthen the time between refinishing, and the improved mar resistance and flexibility should mitigate surface damage due to abrasion and reduce the amount of refinishing of military equipment on the basis of cosmetic appearance.

Testing performed on the panels prepared in the application demonstration verified the exceptional performance that the coating showed in the SERDP effort. The final report [4] contains detailed results.

4.1.4 Accelerated Weathering (All Sites)

Demonstrating the drop-in nature of the WD CARC was the primary reason for this Dem/Val effort, but another was to verify the performance of the product observed during the laboratory-based SERDP effort. Accelerated weathering was performed on test panels prepared during the three application demonstrations to evaluate the color durability of the WD CARC. Four panels from each were subjected to 6,000 hours of ASTM G 155, Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials, using the standard procedure of 108 minutes of light exposure and 12 minutes of light exposure and direct deionized water spray in each 2-hour cycle. Average results for the four panels are plotted in Figure 4, along with data from the baseline Green 383 from MIL-C-46168, and lab batches of MIL-DTL-64159, Type I (siliceous extenders) and MIL-DTL-64159, Type II (WD CARC). The WD CARC exhibits resistance to accelerated weathering that can only be described as exceptional, since the color change after 6,000 hours of exposure is less than the 2.5 units allowed for solvent-borne CARC topcoats after 300 hours exposure, i.e., one-half to two-thirds of the allowable color change after twenty times the exposure period.

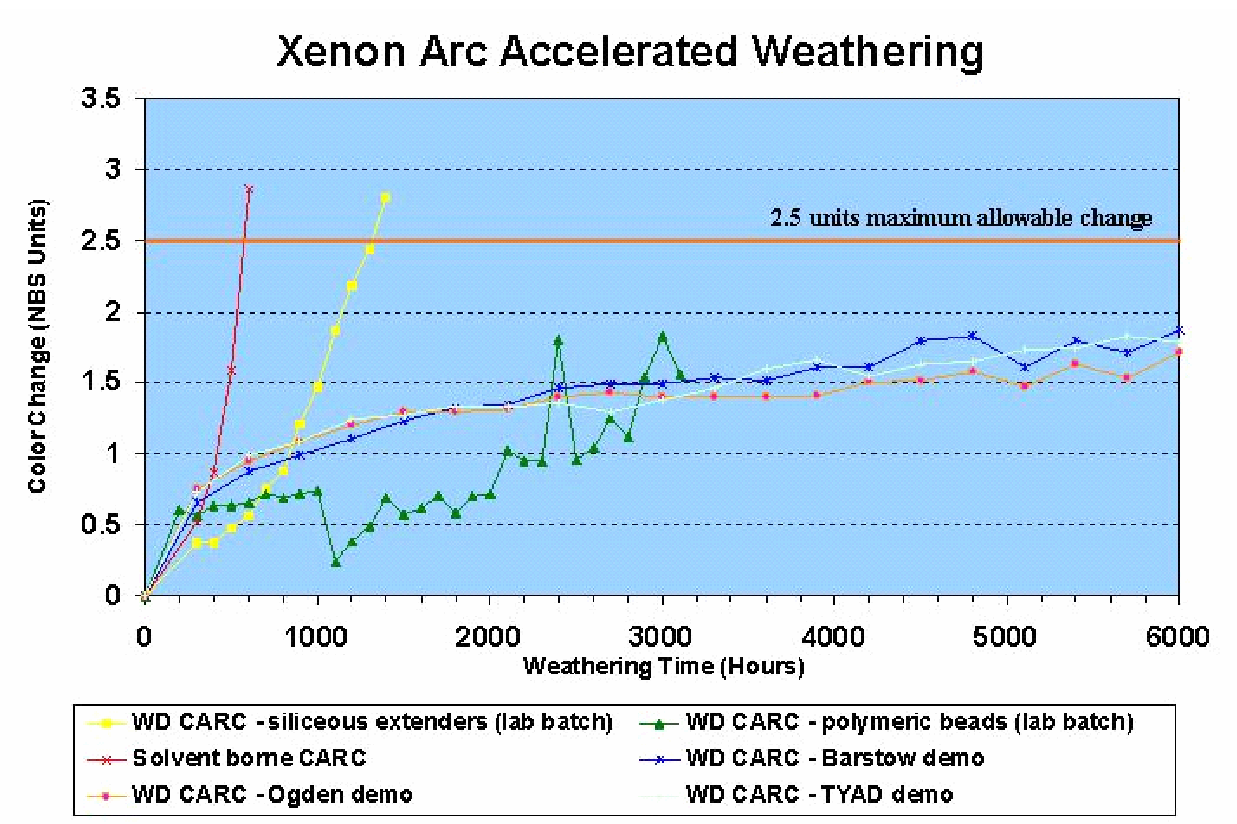

Figure 4. Accelerated Weathering Results for All Demonstrations.

4.1.5 Stripping (All Sites)

A set of panels prepared at each application demonstration was subjected to an accelerated outdoor exposure process (American Society for Testing and Materials [ASTM] D 4141, Procedure C) for a 10-month period before conducting the stripping demonstration. The exposure resulted in a condition that is equivalent to approximately 4 years of natural outdoor exposure. Upon completion of this aging process, the panels were returned to where they were prepared for the stripping portion of the Dem/Val. The stripping trials were conducted by the personnel at each facility responsible for normal production stripping, using the normal protocol. While the data developed to support this Dem/Val are informative, unfortunately these data are not sufficient to support firm conclusions. Comparisons to production data are also limited by the amount of data that could be gathered by this Dem/Val, dissimilarities between the condition of the coatings systems on the production parts and the Dem/Val test materials, and the composition of the coatings systems on the production parts for which the baseline data were developed. On the basis of these data, it appears that a coating system comprising the WD CARC topcoat and MIL-P-53030 primer will be a tough coating system to remove with the processes assessed in this Dem/Val effort. Furthermore, it is not possible to eliminate the possibility that the apparent impact on strippability is due primarily to that particular primer, not necessarily the WD CARC. In most instances, the strippability of this system fell within the production range defined, but generally at the lower end of this range. This trend also seems to be more pronounced in association with the less aggressive DMB processes.

The data produced comparing strippability of the processes tested to support this Dem/Val with similar processes used in the previous study [6] tend to support the conclusions of the previous study. Based on these Dem/Val efforts, and within the limitations stated previously, the use of the WD CARC topcoat will not present a serious impact on the production operations at the three demonstration sites that participated in this Dem/Val or on that of similar processes at other locations. The final report [4] contains the details of the stripping studies.

4.2 PERFORMANCE CRITERIA

Since the demonstrations were designed to show the drop in nature of the WD CARC, performance criteria were established to verify this. In addition, reduction or elimination of pollutants was important. The WD CARC has half of the VOC content of the standard CARC, and contains no HAPs, thus eliminating the methyl isobutyl ketone, methyl isoamyl ketone, toluene, xylene and butyl acetate found in standard CARC. Because the applied film of paint, whether WD CARC or standard CARC, contains no lead or hexavalent chromium, issues associated with stripping residues were comparable. In summary, the major benefits of the switch to WD CARC are that it is a direct HAP-free substitute that performs better at a much reduced VOC emission level. The following table summarizes the criteria as developed in the final technical report for the ESTCP effort. [4]

Table 2. Performance Criteria.

Performance Criteria	Description	Primary or Secondary
Product testing	The tests are listed in the Common Test Descriptions in Appendix B of the Final Report. ASTM methods include D2244, D523, G155, G154, D4541, D2797, and D522.	Primary
Hazardous materials	The HAPs eliminated include methyl isobutyl ketone, methyl isoamyl ketone, toluene, xylene, and butyl acetate. The WD CARC contains no HAPs, and the VOC content is half the standard CARC. No known hazardous materials are introduced with this technology.	Primary
Process waste	The process waste generated by this technology is similar to any coating operation (e.g., equipment cleanup and overspray). Since the nonvolatile portion is similar to standard CARC, no real differences are anticipated.	Secondary
Factors affecting technology performance	The only significant differences observed during the application and stripping demonstrations were the slightly more complex mixing and slower drying of the WD CARC. In addition, the choice of primer may affect the stripping rate of the system.	Secondary
Reliability	No issues	Secondary
Ease of use	Painters had no problem with the mixing procedure, which was similar to that used in preparing MIL-C-46168. They quickly learned how to adjust their application technique from standard CARC to WD CARC. There were no issues with stripping.	Primary
Versatility	The WD CARC should be a drop in product at any facility currently spraying CARC.	Secondary
Maintenance	No issues	*Primary*
Scale-up constraints	No issues	*Secondary*

4.3 DATA EVALUATION

As the demonstration plan indicated, validating the performance of the WD CARC required showing that it could be applied to defense equipment in a production environment, verifying the performance of the applied coating by testing panels prepared during this application process, and demonstrating that it could be stripped economically without affecting normal production processes. Panels were tested by the Naval Surface Warfare Center (NSWC), ARL, and the Air Force Research Laboratory (AFRL). Then, the data from the panels tested during the ESTCP demonstrations were compared to data generated, via the same tests, under the SERDP effort. Performance levels were determined by comparing the results from ESTCP testing with the average and standard deviations observed in the SERDP testing. The statistical comparison allowed for detection of statistically significant differences in the results. Tests identified in current specifications were used to determine pass/fail status, while those not listed in specifications were assessed qualitatively (e.g. worse, same, or better than SERDP results). Table 3 summarizes the results.

Table 3. Expected Performance and Performance Confirmation Methods.

Performance Criteria	Expected Performance Metric (pre demo)	Performance Confirmation Method	Actual Performance (post demo)
PRIMARY CRITERIA (Performance Objectives) (Quantitative)			
Product Testing - Color - Gloss at 60° and 85° - Chemical agent resistance - DS2 resistance - Flexibility - Accelerated weathering - Impact resistance - Tensile adhesion - Abrasion resistance - DMTA	 In accordance with (IAW) MIL-C-46168 IAW MIL-C-46168 IAW MIL-C-46168 IAW MIL-C-46168 IAW MIL-C-46168 IAW MIL-C-46168 None None None None	 ASTM D 2244 ASTM D 523 ¶ 4.4.25 ¶ 4.4.24 ASTM D 522 ASTM G154/155 ASTM D 2794 ASTM D 4541 ASTM D 4060 None	 Acceptable Acceptable Acceptable Acceptable Acceptable Acceptable Acceptable Acceptable Acceptable Acceptable
Hazardous Materials - Target Hazardous Material Eliminated/Reduced - Generated	 Eliminate HAPS Reduce VOCs by 50% None	 Lab Analysis Lab Analysis Lab Analysis	 Acceptable Acceptable Acceptable
Process Waste - Generated	 None	Operating experience	Acceptable
Factors Affecting Performance (Pollution Prevention)	No change from standard CARC	Operating experience	Acceptable
PRIMARY CRITERIA (Performance Objectives) (Qualitative)			
Better durability of part/component	More flexible More durable More durable	ASTM D 522 ASTM G 154 ASTM G 155	Acceptable Acceptable Acceptable
Drop In Replacement	No change from standard CARC	Operating experience	Acceptable
Ease of Use	No operator training required	Operating experience	Acceptable
SECONDARY PERFORMANCE CRITERIA (Qualitative)			
Reliability	No breakdowns	Record keeping	
Safety - Hazards - Protective clothing	No change from standard CARC	Operating experience	Acceptable
Versatility - Other applications	Yes, by any facility currently using standard CARC	Operating experience	Currently in use by the United States Marine Corps (USMC) and Canada military
Maintenance - Required - Eliminated	No change from standard CARC	Operating experience	Acceptable
Scale-Up Constraints - Engineering - Flow rate	No change from standard CARC	Operating experience	Acceptable

4.4 TECHNOLOGY COMPARISON

As noted in Section 4.1, the WD CARC is not only a drop-in substitute for the standard CARC currently in use at most depot facilities, but it also exhibits performance that is far superior. That alone may be sufficient reason to switch, but the underlying environmental factors that led to its development were the much-reduced VOC content (about half that of current CARC) and the elimination of HAPs. ARL is currently investigating the technology of MIL-C-53039, the single-component, moisture-cured CARC. Reformulation with exempt solvents can provide a CARC that is comparable to the WD CARC in the VOC content and is HAP-free solvent. At this point, however, the dramatic improvement in the performance of WD CARC generated by the incorporation of the polymeric beads has not been duplicated in the MIL-C-53039. Consequently, the WD CARC will be the focus of implementation efforts.

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5.0 COST ASSESSMENT

5.1 COST REPORTING

Since the goal of this effort was to demonstrate that the WD CARC was a drop in replacement for the solvent-based CARC used by the three participating activities, the cost reporting and assessment focused on the differences discovered that could be attributed to the change in coatings. The differences can be condensed to those noted in the performance assessment above, i.e., the WD CARC has half the VOC content, eliminates HAPs from the formulation, sells for a slightly higher cost, and provides exceptional improvement in performance (based on laboratory results on test panels). There is no field data yet to confirm the performance improvements expected, although the team plans to track the equipment coated in the demonstrations. Consequently, assumptions about the economic benefits will be based on relatively simple protocols and data gathered at a selection from the demonstration sites. From a production standpoint, the startup costs were shown to be minimal; no additional equipment was needed for the new technology demonstrations; there were no observable differences due to application of WD CARC for process labor, maintenance, consumables, utilities and production rates; and costs for the new technology in the area of compliance and environmental management should be minimal due to the elimination of hazardous air pollutants from the formulation. Examples based on two of the demonstrations are included in Section 5.2.

5.2 COST ANALYSIS

Barstow MCLB

The cost of the WD CARC and data on the other topcoats approved for use on USMC tactical vehicles and support equipment, are shown in Table 4. The paint cost data was provided by the paint manufacturer (Sherwin Williams) that participated in this ESTCP-sponsored demonstration. Based on observations made during the application process, the differences in process variables between the two coatings is minimal, and the amount of time and material required to paint a vehicle with MIL-C-29475 is essentially identical to that of WD CARC. Thus, application-related labor and the overhead and facilities costs do not have an effect on this analysis. Because of its qualitative nature, the anticipated lower usage of WD CARC (up to one-third less than standard CARC) was not factored into Table 4.

Table 4. Cost Analysis Based on Paint Materials Cost and Coverage.

Product Name	Admixed (% Solids)	$/Gal (100 gal order)	Coverage 1 mil DFT (Sq Ft)	$/Sq Ft (@ 1 mil DFT)	$/Sq Ft (@1.8 mils DFT)	$/Sq Ft/Yr (@ 1.8 mils DFT)
MIL-DTL-64159, Type II	39.8	51.67	638.392	0.08094	0.14569	0.01619
MIL-C-46168D, Type IV	38.1	47.30	611.124	0.07740	0.13932	0.02322
MIL-C-53039	51	38.00	818.04	0.04645	0.08361	0.01394
MIL-C-29475	48.2	44.61	773.128	0.05770	0.10386	0.01731

Notes: Coverage data is based on 100% application transfer efficiency.
Recommended DFT for all CARC is 1.8 mils (minimum).
Paint life cycle is based on the following data: 9 years for 64159 Type II versus 6 years for others.

Based solely on cost per gallon of the various paints for a 100-gallon order, these values range from $38.00 for the MIL-C-53039 to $51.67 for the WD CARC. The cost per square foot at the recommended DFT (1.8 mils) ranges from $0.08361 for the MIL-C-53039 to $0.14569 for the WD CARC. Thus, assuming that a vehicle has a wetted surface of 1,000 square feet, it would cost $83.61 for the MIL-C-53039 versus $145.69 for the WD CARC, based on the cost and the theoretical coverage characteristics of the paint. This does not reflect the reduced amount of paint required as documented at the other sites, primarily due to the equipment problems (oil contamination) noted in Section 4.1. The cost per square foot of MIL-C-29475 (the current standard topcoat used at MCLB Barstow) would obviously fall between that of the MIL-C-53039 and WD CARC.

The cost analysis above is more relevant to immediate or short-term costs, while a long-term or life-cycle cost analysis would certainly take into account the durability or frequency of repainting required. Based on laboratory-generated data, which indicates the superior weatherability (greater than 6 times exposure duration), abrasion resistance (approximately 3 to 4 times less weight and thickness loss), and flexibility (approximately 3 times impact resistance) of the WD CARC compared to the standard CARCs, it could be assumed that an increase in life span up to 800% can be obtained. While vehicle overhaul frequency is usually based on the requirements set by commanding officers and/or vehicle usage duration/mileage, it is estimated that these types of vehicles generally receive depot level repainting every 6 years. Using a conservative estimate that the durability enhancement offered by the WD CARC would produce a 50% increase in life span (instead of a liberal estimate of 800% based on laboratory data), the average vehicle repaint cycle would be increased from about 6 years for the standard system to 9 years for the novel WD CARC system. As shown in Table 4, the cost per square foot per year of service for the WD CARC drops to a level that is less than both the MIL-C-46168 and the MIL-C-29475. It is important to note that while the data for the MIL-C-53039 material in Table 4 indicates that the MIL-C-53039 CARC is the most cost effective, the price per gallon of the WD CARC is expected to decrease significantly with full-scale production and wide-spread implementation. This economic and manufacturing equilibration should negate and probably surpass the cost advantage currently held by the MIL-C-53039 material. As noted above, the superior performance of the WD CARC has not been duplicated in the MIL-C-53039 material.

Other factors, not included in the above cost analysis, that would affect cost can be attributed to decreased VOC emissions, decreased waste generation, and increased worker safety. Cost avoidance in the form of fines from regulatory agencies up to $25,000 per day per facility (in certain environmental or process scenarios) can be realized by facilities that implement the low-VOC WD CARC in lieu of using any of the higher VOC CARCs. By implementing this type of low VOC technology versus the higher VOC CARCs, the high cost of implementing hard controls (i.e., thermal incinerators, catalytic converters, regenerative oxidizers, adsorption filter equipment, etc.) can be avoided. These controls can cost up to $5M per depot facility along with the associated operating costs (which can be as high as $250,000 per year per facility). Also, VOC credits can be generated from the reduction in tons of VOC emitted by a facility, which vary in value from state to state with respect to ozone nonattainment areas.

Ogden ALC

The paint and depaint facilities for applying CARC to the MEP units have been changed to Building 843. The facilities are state-of-the-art for paint application and removal. However, the coating application and removal processes are similar to those used in the Dem/Val effort. The Dem/Val results should apply for CARC application in the new facility.

Ogden ALC personnel estimate that when the Building 843 painting operations are working up to speed, they will be painting approximately 200 to 250 generator sets requiring CARC per year. This includes MEP-005A, MEP-006A, MEP-007B, and MEP-009B units. Additionally, Ogden ALC personnel support remote location paint jobs and unknown items that require CARC application. These are estimated to account for 25 to 40 items requiring CARC. Based on their experience, Ogden ALC personnel estimate that it takes approximately 1 gallon of the solvent-borne CARC to cover an MEP unit.

Based on a yearly requirement of 200 units plus an additional 25 remote location CARC coating jobs and other unknown units, there would be a requirement for 225 gallon kits of CARC per year. Using a price of $47.30 per gallon kit of solvent-borne CARC translates into a cost of $10,642.50 per year for use by Ogden ALC. Estimates from the suppliers of the low-VOC WD CARC place the cost of gallon kits at $51.67 per kit. Based on the coverage exhibited during the application demonstration, where 3 gallons of the low-VOC WD CARC were required to cover the four MEP units, similar coverage increases can be expected with implementation of the low-VOC WD CARC by Ogden ALC. That would translate into a yearly usage of 150 gallons of low-VOC WD CARC by the ALC. The yearly cost of using the low-VOC WD CARC would be $7,750.50. Thus, Ogden ALC could save almost a third of its CARC costs by switching to the low-VOC WD CARC. This analysis does not include improvements in weathering, wearability, and other mechanical property improvements demonstrated in laboratory testing by the low-VOC WD CARC. These would lower the in-service costs because of fewer touch-ups between programmed depot maintenance (PDM) cycles.

Since the WD CARC uses polymeric bead extenders in place of silica extender pigments (which are contained in all the other CARC topcoats), health-related ailments of maintenance workers exposed to air-borne silica (i.e., silicosis) would be avoided along with the associated costs related to health remediation and litigation. Utilization or realization of any of these

environmental cost benefits individually or collectively would easily decrease the overall cost of the WD CARC to significantly less than the other standard CARC topcoats from a life-cycle standpoint.

5.3 COST COMPARISON

Based on Barstow MCLB data

CARC-related paint and de-paint waste generation has been found to be approximately 3,000 tons per year in the DoD. Based on waste disposal costs of $0.35 per pound and extending life cycle from the current 6-year average to an estimated 9-year average, approximately 1,000 tons and $700,000 for the entire DoD or about $70,000 per depot per year would be saved. Based on previously presented information, which takes into account the total processing cost of painting three types of vehicles (Table 5), it is estimated that the total cost of painting (excluding cost of waste disposal discussed above) is $1.14 to $2.2 million per year per facility. Thus, a 50% increase in life cycle from 6 to 9 years produces cost savings of $0.38 million to $0.73 million per year per facility, depending on the type of vehicles repainted.

Table 5. Cost Analysis Based on Painting Cost and Life-Cycle Extension.

Material	Prepare Surface (MH)	Paint (MH)	Labor Cost ($)	Topcoat Used (gal)	CARC Topcoat Cost @ $40/gal	Primer Used (gal)	Primer Cost @ $25/gal	Total Material Cost ($)	TCOP ($/unit)	TCOP 480 Units/ Year ($M)	Cost Savings/ Year ($M)
HMMWV	18	9	1890	10	400	3	75	475	2365	1.14	0.38
M-1 Tank	24	12	2520	13	520	4	100	620	3140	1.51	0.50
HEMMT	48	16	3780	17	125	5	125	805	4585	2.20	0.73

Notes: Depot labor estimated at $70/hour (actual range $65–$80).
Depot processing rate estimated to be ∼40 units per month per depot.
TCOP = total cost of painting.
Cost savings based on 50% life-cycle extension (i.e. 6 years to 9 years).

6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

Since the basis of this Dem/Val was essentially a material substitution, cost observations focused on differences that could be attributed to this change, i.e., balancing the present higher cost of the WD CARC against its exceptional improvement in performance and subsequent longer service life. Due to the drop-in nature of the new technology, the startup costs were shown to be minimal, with only a brief initial fine-tuning or practice session to enable the paint operators to perfect their technique and make adjustments (fluid fan width, fluid nozzle size, air line pressure, and stand-off distance) before spraying equipment and panels. No additional equipment was needed for the new technology demonstrations. There were no observable differences because of application of WD CARC noted for process labor, maintenance, consumables, utilities and production rates. Costs for the new technology in the area of compliance and environmental management should be minimal because of the elimination of hazardous air pollutants from the formulation. Compliance audits, hazardous waste management plan development and maintenance, toxics release inventory (TRI) reporting and Occupational Safety and Health Administration (OSHA) training requirements may be reduced after implementation.

6.2 PERFORMANCE OBSERVATIONS

As a replacement for the standard CARC topcoats, the WD CARC has proven to be a drop-in replacement providing significant environmental benefits and superior performance. By design, it was applied in production environments under a wide variety of environmental conditions, ranging from the low-humidity California desert to the warm and humid summer in Utah to the cool and humid fall in Pennsylvania. When the coating components had been separately mixed, then combined with the appropriate mixing equipment, reduced with water to spray viscosity, and poured into the application equipment, painters were quickly able to adjust their application techniques to the new product. The WD CARC used was from production batches manufactured by the Sherwin-Williams Company, and it was applied using standard production equipment (typically HVLP equipment) under normal environmental conditions, and the operators used their standard PPE.

These application studies have verified that the same equipment currently used can be used to accommodate the new WD coating. However, the WD material has different spray characteristics than the solvent system currently used and requires different process parameters to achieve acceptable results. Experience from the three application demonstrations indicated that these differences were easily and rapidly overcome by experienced painters. In addition, stripping tests from the ESTCP effort have shown that there are differences in the rate of coating removal with several different blast media when compared to the standard CARC. Depending on substrate and the specific media employed, the rate of stripping can be either greater or less than that of standard CARC. Similarly, the rate of WD coating removal when chemical strippers are employed can be greater or less than that of standard CARC, depending on the particular stripper employed. Although not observed in any of the application demonstrations, experience with waterborne coatings indicates that they are often more susceptible to problems with substrate cleaning and pretreatment. Finally, environmental representatives at TYAD made the

observation that a facility not currently using waterborne coatings could conceivably have a new (waterborne) waste stream to deal with.

The time required to clean the application hardware was also unaffected. Test panels prepared during the application demonstrations have validated the exceptional performance noted in the laboratory-sized SERDP effort, especially its flexibility, mar resistance, and outdoor durability. This improved performance should lengthen the time between refinishing cycles, mitigate surface damage due to abrasion and result in less refinishing of military equipment on the basis of cosmetic appearance. In addition, the further test results on these panels indicated that production stripping processes will be essentially unaffected by the conversion to WD CARC.

6.3 SCALE-UP

There are no scale-up issues because it was the purpose of this Dem/Val to verify the drop-in nature of the WD CARC in a production environment for both application and stripping processes, and all of the demonstrations used full-scale production equipment.

6.4 OTHER SIGNIFICANT OBSERVATIONS

Although production application and stripping operations were demonstrated to be essentially unaffected by switching from standard CARC to WD CARC, there are some changes that should be mentioned. First, the mixing process must be followed exactly, that is, after separate mixing of the A (polyester) and B (isocyanate) components, they must be combined by adding component B to component A, followed by fairly energetic mixing with a “squirrel cage” mechanical stirrer until the blend is completely homogeneous. Then, and only then, can the thinner (deionized water) be added to achieve proper spray application viscosity. Premature addition of the water or insufficient mixing of the component A and component B blend will cause coating failure (at the worst) or unacceptable performance (at best). It should be noted, however, that improper preparation of the solvent-based CARC also leads to poor results, but following the manufacturer’s technical data sheet and the directions on the containers will eliminate this issue. Second, since water is the primary “solvent” in the WD CARC after reduction for spray application, it is to be expected that drying is somewhat slower. However, once the coating has dried, the ultimate, full-performance cure is achieved at the same point as with standard CARC, about a week at typical ambient conditions. If the drying process must be accelerated, the applied coating may be force-cured at temperatures up to approximately 200º F. Baking the product at higher temperatures is not recommended because ARL has preliminary indications that the chemical agent resistance is adversely affected at higher cure temperatures.

6.5 LESSONS LEARNED

The ESTCP low-VOC team was fortunate in being able to execute six demonstrations (three each for application and stripping) without major problems, but only because of thorough advance planning. The normal schedule for an application demonstration was to apply the pretreatment and primer to the equipment and test panels on the day before the application of the WD CARC, either in the presence of the ESTCP team or before their arrival. The topcoat application was performed the following day, and an additional day was reserved for

examination of the coated panels and equipment, preliminary measurements of film properties on the hardware such as dry film thickness and gloss, application of topcoat to remaining equipment and/or outbriefings. Each stripping demonstration was set up for a single day with one backup for examination of panels in chemical stripper baths (if applicable) and outbriefings. In addition, selection of a site from each of the participating DoD activities ensured that a broad range of equipment could be painted. In demonstrating the drop-in properties to potential users, at least two complications occurred. First, process changes (i.e., a change in the CARC primer or a change in the building used) made in the interval between the baselining performed under the SERDP effort and the applicable demonstration performed in the ESTCP effort made a direct scale-up comparison difficult, but they did not affect any performance conclusions. Second, as a result of laboratory and production experience, the team strongly recommends that applicators always prepare complete kits of the coating for application. With the chemical warfare survivability requirement being so critical in CARC, the risk of improper volumetric ratios is too high to consider use of less than a full kit. Simply pick the right kit size for the job at hand. Finally, the stripping demonstration at Ogden was delayed about a month in the aftermath of 9/11/2001, but Ogden and the Air Force were extremely helpful in rescheduling it on such short notice.

6.6 END-USER/ORIGINAL EQUIPMENT MANUFACTURER (OEM) ISSUES

End users of this technology include program managers, OEMs, and depots that are required to follow Army Regulation 750-1, [2] which is also followed by the USMC, for chemical warfare survivability. This means that all tactical equipment (including combat, combat support, essential ground support equipment, tactical wheeled vehicles, and aircraft) must be hardened against performance degradation caused by chemical warfare agents or decontamination procedures. Therefore, virtually everything in the Army and Marine Corps inventory and Air Force vehicles and equipment procured through the Army require agent resistance.

A new specification, MIL-DTL-64159 (dated January 20, 2002), was prepared and published shortly after the conclusion of this ESTCP Demonstration Project. This specification will provide a means of procurement of the new topcoat. The QPL for the specification, QPL-64159, was first published February 28, 2002, and the current revision includes four suppliers. In addition, ARL has completed revision of the CARC quality control and application specification, MIL-DTL-53072C (formerly MIL-C-53072B), to incorporate MIL-DTL-64159. NSNs are available for four different kit sizes and are included in MIL-DTL-53072C. Many facilities, both DoD and OEM, have indicated that they use MIL-DTL-53072 to implement CARC, and inclusion of MIL-DTL-64159 will facilitate use of the WD CARC technology.

The Army is moving quickly to implement this coating system. Army Personnel Armor System, Ground Troops (PASGT) helmets made by MSA Gallet employ this coating. Modifications to contracts are being enacted to permit project managers (PMs) of programs such as Bradley, Abrams, M113 family of vehicles (FOV), heavy expanded mobility tactical truck (HEMTT), and Stryker to paint their vehicles with WD CARC in place of the existing solvent-based CARC (MIL-C-46168 and/or MIL-C-53039). Additional efforts are ongoing with the Army aviation community to use this coating for aircraft, and it has been demonstrated at various locations, including at Sikorsky on a Blackhawk. The USMC has fully implemented WD CARC at all of

their facilities worldwide, including Albany MCLB, Barstow MCLB, Pearl Harbor Naval Shipyard, and the Okinawa USMC base. Typical Marine Corps assets now being painted with WD CARC include the LAV-AT, HMMWV, and advanced amphibious assault vehicles (AAAV). Finally, the Canadian Department of Defense is using this paint on many of their military vehicles as well

6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

The primary motivation for developing reduced-VOC protective coatings in general and WD CARC in particular, has been regulations evolving from the Clean Air Act (CAA) and its amendments. As noted in Section 1.3, state and local governments can and often do set limits lower than those in the CAA. Although initial guidance from EPA had indicated that the MMPP NESHAP would apply to CARC, at this point, it appears that DoD will have its own NESHAP, Defense Land Systems and Miscellaneous Equipment, that will nonetheless still regulate HAP content of the protective coatings used for military equipment. Additional drivers, from a broader perspective, arise from Executive Orders (EO), such as EO 11738, “Providing for administration of the Clean Air Act and the Federal Water Pollution Control Act with respect to Federal contracts, grants or loans,” EO 12856, “Federal Compliance With Right-to-Know Laws and Pollution Prevention Requirements,” and EO 13148, “Greening the Government Through Leadership in Environmental Management.”

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APPENDIX A

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